EXPERIMENTS WITH E. H. LAND'S TWO-COLOR PROJECTION

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Summary

Since the quality of E. H. Land's two-color pictures has been subject to discussion, two groups of students were asked to judge the quality of Land's pictures. The preparation of the slides and the experimental setup is described. The results show the inferiority of E. H. Land's system in its actual form to ordinary tricolor projection. From the results it appears that the mechanism of color transformation works well with most people tested, but that the lack of information contained in the slide photographed through the blue filter is considered serious. An interesting detail is that a minority of people can detect very little or no difference between the two forms of projection.

Introduction

Since E. H. Land published the results of his work on two-color projection[1], various publications have dealt with the aspects of his work.[2,3,4,5,6] Generally, the quality of E. H. Land's pictures was considered inferior to that of ordinary tricolor projection, these results being in contrast with Land's original statements where he described the quality of his pictures as that of a good color-slide. Because the quality of a picture is a matter of rather subjective judgment, there seems to be a considerable lack of statistical data about this question. Therefore, we considered it worthwhile to show Land's pictures to a number of students and to have them give their judgment of the quality.

Preparation of the Slides

E. H. Land made his experiments with slides prepared for ordinary tricolor projection. With such slides care must be taken to get an equal contrast in every one of the three pictures taken through different filters. The γ, the photographic measure of contrast, should be close to unity. We obtained γ's of 1.07, 1.19 and 1.26 respectively for the green, red and blue color separation slides. The color separations were obtained through Kodak Wratten filters as follows: No. 58 (green), No. 24 (red) and No. 47B (blue). We photographed six posters, which show color photographs of landscapes and other natural scenes, and which will be numbered 1 to 6, and two abstract pictures with spots of different size and color, numbered 7 and 8. Fig. 1, Fig. 2 and Fig. 3 show the red, green and blue color separation slides respectively.

Experimental Setup

Two experiments were undertaken. The second experiment was undertaken, because the authors considered the number of students of the first experiment as too small for obtaining conclusive results. Also experiment No. 1 showed some slight modifications for improving tricolor projection. Moreover, we changed the order of the projection systems to investigate a possible effect on judgment. In each of the two experiments we used the following projection systems:

a) E. H. Land's projection.
b) Tricolor projection omitting the blue color separation slide, this will be called red-green projection.
c) Ordinary tricolor projection.
d) The original posters were shown in ordinary daylight.

The conditions of the two experiments are stated in Table 1.

A questionnaire was given to each student in which he had to inscribe a note for the quality of color reproduction of each picture, the meaning of the note being:

6	excellent
5	good
4	passable
3	bad
2	very bad
1	not usable

The students were also required to identify certain colors in the pictures.

Evaluation of the Results

In each questionnaire we averaged all the notes given for the pictures of a single projection system. So we obtained four average notes in each questionnaire. Fig. 4 and Fig. 5 show how many times each average note occurred for each projection system for experiment No. 1 and No. 2 respectively. A characteristic of Land's projection is the broad distribution of the average notes, from judgment "good" to judgment "very bad" one finds every judgment, but in the whole Land's and red-green projection are judged worse than tricolor projection. The fact that the first pictures were shown by tricolor projection seems to have shifted the judgment of Land's projection to the bad side in experiment No. 2, whereas the judgment of tricolor projection was not affected substantially by the slight changes of experimental conditions. It is seen that no perfect tricolor projection has been obtained;

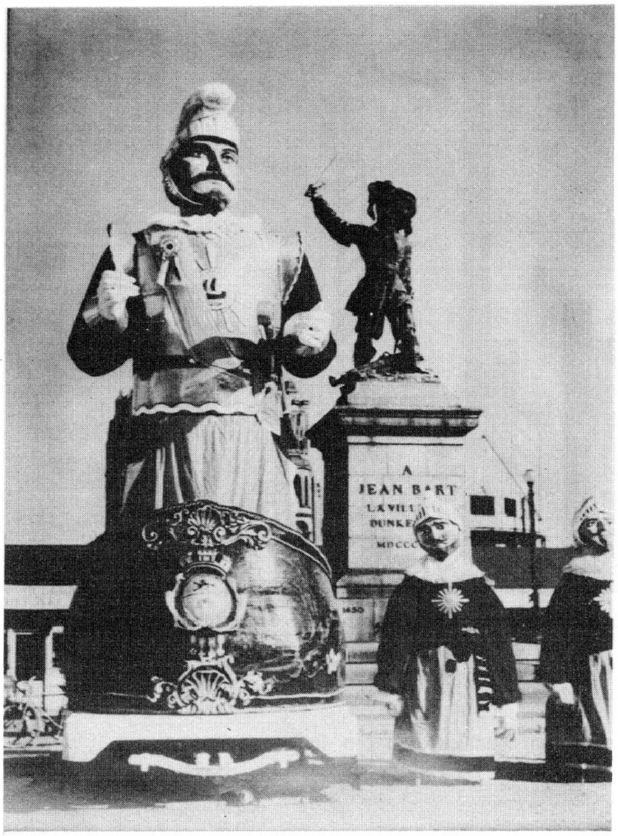

Figure 1—Red separation slide of picture No. 5.

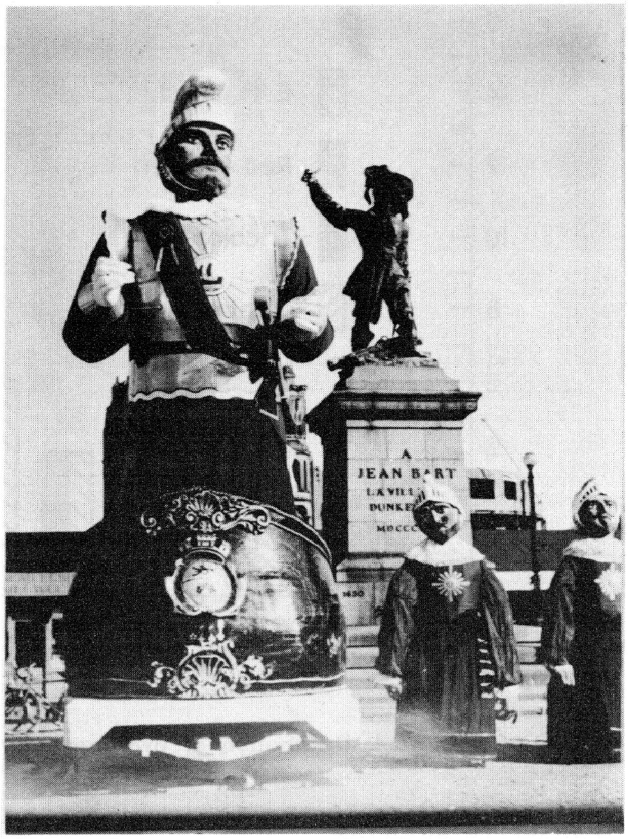

Figure 2—Green separation slide of picture No. 5.

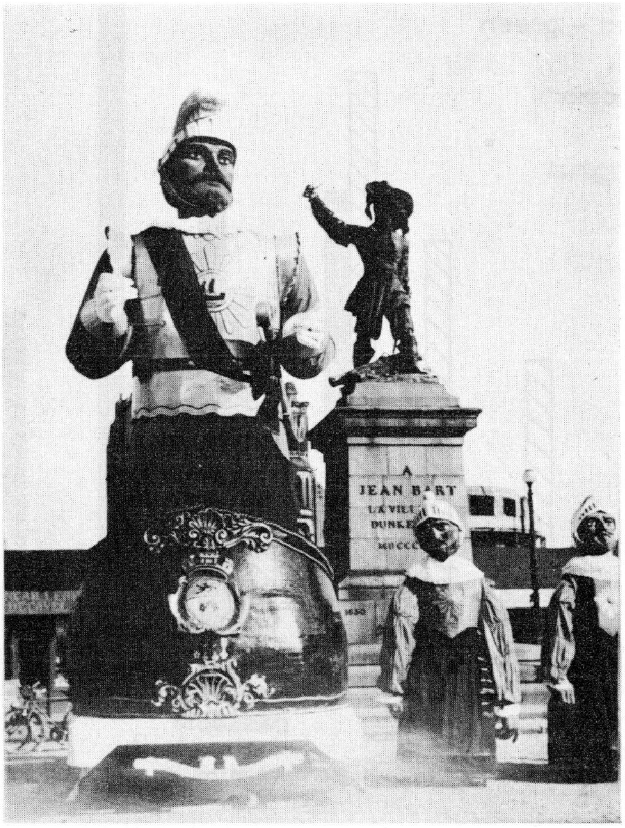

Figure 3—Blue separation slide of picture No. 5.

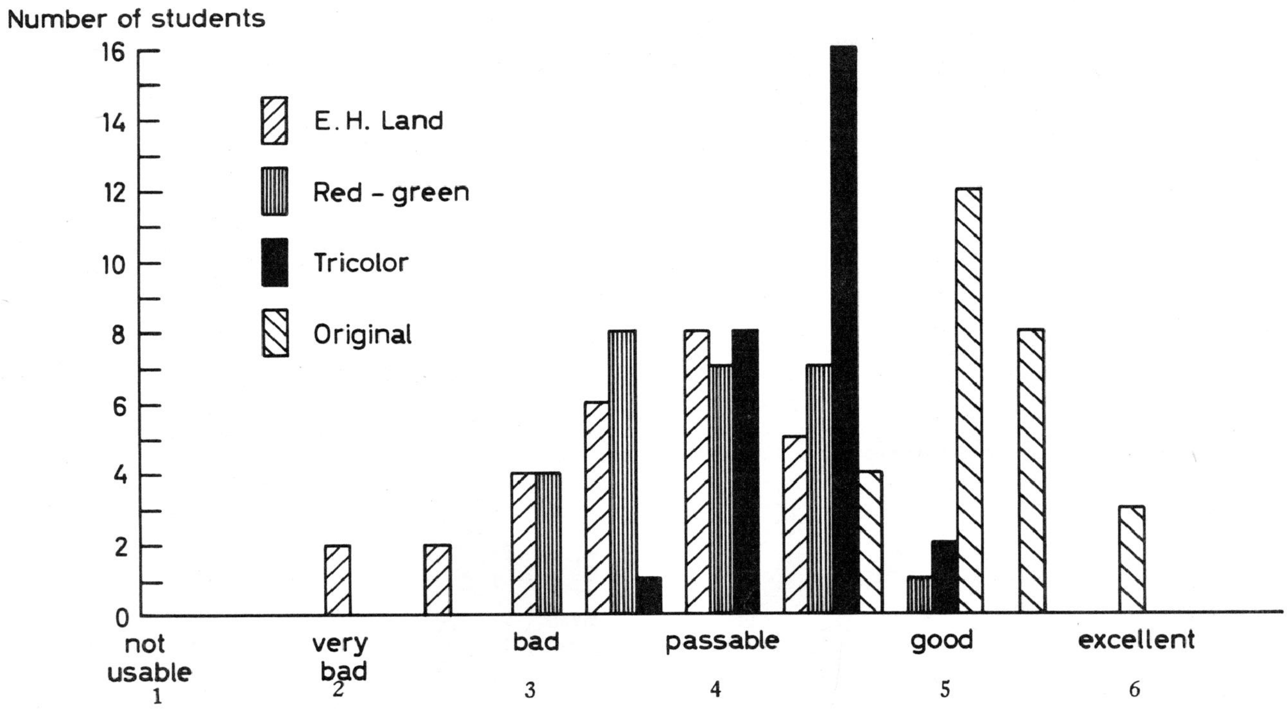

Figure 4—Distribution of average judgments of each projection system in experiment No. 1.

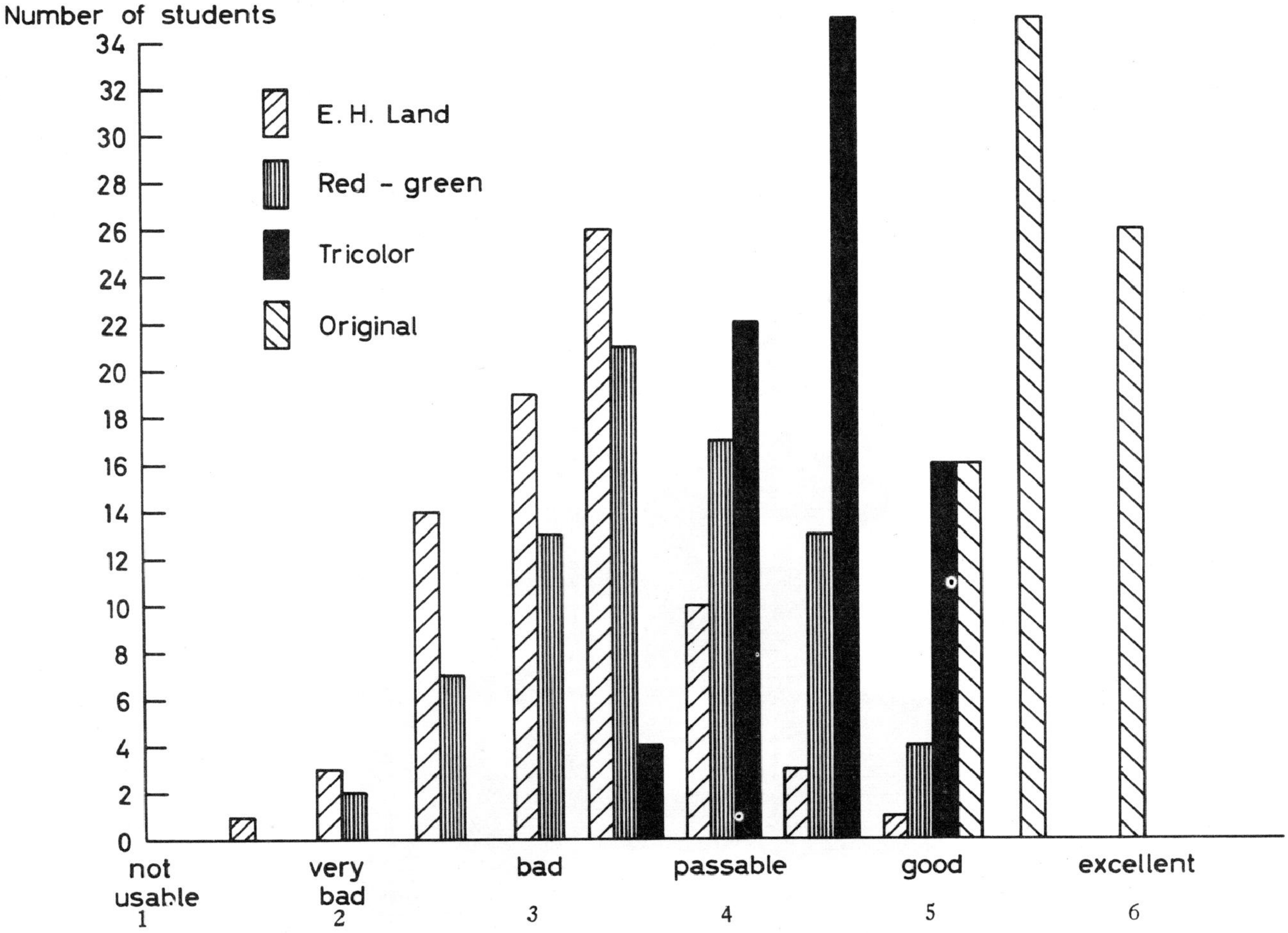

Figure 5—Distribution of average judgments of each projection system in experiment No. 2.

TABLE 1: EXPERIMENTAL CONDITIONS IN THE TWO EXPERIMENTS

	Experiment No. 1		Experiment No. 2	
Order of pictures	Projection system	Pictures	Projection system	Pictures
	E. H. Land	1 - 8	Tricolor	1 - 3
	Red-green	4 - 8	E. H. Land	4-8, 1-3
	Tricolor	1 - 8	Red-green	7-8, 4-6
	Original	1 - 6	Tricolor	4 - 8
			Original	1 - 6
Filters used	Wratten No. 24, 58, 47B		Wratten No. 24 for Land's projection, Wratten No. 25, 58, 47B for the other projection systems.	
Reduction of white light	For Land's projection the white light was reduced to a quarter of its original intensity by a diaphragm.		Same as experiment No. 1	
Brightness of screen without any slides inserted	11 footcandles for Land's projection. 6.5 footcandles for tricolor projection.		11 footcandles for Land's projection. 5.5 footcandles for tricolor projection.	
Number of students	32		84	
Eliminated because they stated color blindness	5		6	
Not usable for evaluation	-		1	

TABLE 2: DISTRIBUTION OF THE DIFFERENCES BETWEEN THE AVERAGE NOTE OF THE FIRST THREE TRICOLOR PICTURES AND THE FOLLOWING THREE PICTURES SHOWN BY E. H. LAND'S PROJECTION IN EXPERIMENT NO. 2.

	Number of Students
No difference or E. H. Land's projection better	4
Less than 0.5 points	9
Less than 1 point	9
Less than 1.5 points	25
Less than 2 points	21
Less than 2.5 points	8
More than 2.5 points	1

TABLE 3: NUMBER OF CORRECT RESULTS OF IDENTIFICATIONS OF COLORS IN ABSTRACT PICTURES 7-8. THE NUMBERS WHICH REPRESENT MORE THAN 50% OF THE AUDIENCE ARE BOLDFACED.

Type of projection → Color ↓	E. H. Land	Red-green	Tricolor
Red	60	68	70
Orange	20	5	5
Light Brown	17	69	75
Yellow	2	54	77
Green	13	72	76
Blue-green	5	5	27
Dark Blue	1	1	26
Light Blue	3	0	22
Violet	15	8	64
Purple	3	12	71

TABLE 4: NUMBER OF CORRECT RESULTS OF IDENTIFICATIONS OF COLORS IN PICTURES 1 - 6. THE NUMBERS WHICH REPRESENT MORE THAN 50% OF THE AUDIENCE ARE BOLDFACED. THE COLORS MARKED WITH X WERE NOT SHOWN. (SEVERAL RED AND BLUE OBJECTS WERE SHOWN; THEREFORE, THERE ARE THREE LINES LABELLED RED AND TWO LINES LABELLED BLUE).

Type of projection → Color ↓	E. H. Land	Red-green	Tricolor	Original
Red	76	73	72	75
Red	69	66	46	74
Red	55	x	17	75
Yellowish Brown	47	x	77	77
Yellow	9	43	68	77
Yellowish Green	0	x	59	78
Yellowish Green with touch of Brown	45	x	48	75
Greyish Blue	35	x	77	77
Blue-green	40	x	77	77
Blue	38	30	72	78
Blue	1	21	65	76
Blueish Grey	33	21	53	73

however, the quality of it can be compared with that evaluated during NTSC - Color television field tests, as shown in Figure 8 of reference 5.

In experiment No. 2 we evaluated the average note of the first three pictures shown by tricolor projection and calculated the difference to the average note of the following three pictures shown by Land's projection in each questionnaire. Table 2 shows the distribution of these differences. Remarkable are the first group of four and the second group of nine students. Their average judgment of tricolor projection has about the same distribution as that shown in Fig. 5; i.e., these little differences are not due to a worse judgment to tricolor projection. Nine of these thirteen were willing to be examined by an oculist. There could not be found any student with an anomaly of color sense.

In experiment No. 2 we evaluated the number of correct names of colors which is shown in Tables 3 and 4. This evaluation was done by one of the authors judging whether a name should be considered right or wrong. The identification of colors in tricolor projection and the original pictures gives a certain control of this rather subjective method. The identification of colors in the abstract pictures did give a greater number of incorrect results. On the one hand this may be due to association of certain colors with certain objects, on the other hand the margins for correct denominations had to be wider for pictures 1 - 6 as spots on these pictures did not show so uniform a color.

Conclusions

Dr. Land's projection was judged inferior to ordinary tricolor projection. The little differences between red-green and Land's projection seem to indicate that the mechanism of color transformation works well with most persons tested, when looking at "natural scenes", as Land calls it. It seems to fail when looking at the abstract pictures, as the high rate of uncorrect color identifications seems to indicate. The loss of the information contained in the slide photographed through the blue filter seems to be serious.

The authors hope to have evaluated some statistical material, which might be useful for further discussion considering the application of Land's projection system. They did not intend to deal with the theoretical aspects of Land's work. They are aware that they have not shown the inferiority of any two-color system to the tricolor system but only the inferiority of two two-color systems to the tricolor system. However, they do not consider it very probable that sometime a two-color process might be found, which will give the spectator the same appearance as tricolor projection.

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